ACKNOWLEDGMENTS

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APPENDIX I. REFERENCES

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APPENDIX II. NOTATION

The following symbols are used in this paper:

L_{15} = 15th-percentile legibility distance;
LD_{VMS} = minimum required legibility distance for variable message signs;
N = number of words in message (excluding prepositions);
N_{max} = maximum allowable number of words in message (excluding prepositions);
RD_{VMS} = minimum reading distance for variable-message signs;
T_a = time available to read sign;
T_r = time required to read sign;
t_w = minimum reading time per word (use 1.0 s per word for variable message signs);
v = prevailing traffic speed; and
W = workload ratio.

CHARACTERISTICS OF TRIPS BY FOOT AND BICYCLE MODES IN INDIAN CITY

By V. Thamizh Arasan,[1] V. R. Rengaraju,[2] and K. V. Krishna Rao[3]

(Reviewed by the Urban Transportation Division)

ABSTRACT: Walking and bicycling are the two modes predominantly used for travel in urban areas of developing countries, and the location of transport-related facilities in urban areas thus is influenced by the characteristics of these modes. The promotion of trips by these nonmotorized modes will also help, to a significant extent, in energy conservation and environmental protection. Herein, the home-based walking and bicycling trips of Tiruchirapalli, India are analyzed with respect to trip length, and the influential variables like age, sex, occupation, trip purpose, and time of day of travel. Significant variations in trip lengths by walk and bicycle were found to exist among trip makers of different categories. As walking and bicycling modes cannot be used for longer trips, it is necessary to determine the acceptable trip lengths by the two modes. The acceptable trip length for these modes was found by fitting polynomials to the trip-length distributions. Use of probability distributions for determining the acceptable trip length has also been illustrated in selected cases.

INTRODUCTION

The structure of an urban area may be said to be a particular articulation of different land uses that might exist in the area. A critical element of an urban structure is the configuration of the transport network. The primary objective of urban planning is to locate different land uses such as residential areas, workplaces, schools, shopping centers, and recreational centers, in conjunction with the transport network and with due consideration to the environmental aspects, in such a way that the interaction between these land uses is facilitated with minimum intensity of travel both in terms of number and length of trips. Further, it is desirable, particularly in developing countries, that these trips, to the extent possible, are made by nonmotorized modes such as walking or bicycling, which in turn will help energy conservation and environmental upgradation to a significant extent. In Indian cities, like in most other developing countries, trips by foot and bicycle account for a significant proportion of total trips. In this context, analysis of certain basic characteristics of walking and bicycling trips may be very useful.

A few attempts have been made earlier to analyze urban trips on foot. Morrall and Lam (1982) measured walking distances to and waiting times at bus stops. They performed statistical analysis of the data and reported mean walking distances. They have also suggested redefinition of bus-pas-

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[4]Note. Discussion open until September 1, 1994. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on February 19, 1993. This paper is part of the ***Journal of Transportation Engineering***, Vol. 120, No. 2, March/April, 1994. ©ASCE, ISSN 0733-947X/94/0002-0283/$2.00 + $.25 per page. Paper No. 5654.

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TABLE 1. Trip Details of Study Area

Mode (1)	Percentage of Trips for Different Purposes: Work (2)	School (3)	All (4)
Walking	52.5	80.9	64.7
Bicycling	25.5	5.1	15.8
Public transport	15.1	10.9	14.2
Private transport	6.2	1.4	4.2
Intermediate public transport (auto rickshaw, cycle rickshaw, taxi)	0.7	1.7	1.1

TABLE 2. Trips Made by Different Age Groups and Sex

Group (1)	Proportion of trips (%) (2)	Trip Length in Minutes: Mean (3)	Mode (4)	Standard deviation (5)
(a) Sex				
Male	64.8[a]	16.1[a]	12.7[a]	7.3[a]
	100.0[b]	18.8[b]	15.2[b]	8.2[b]
Female	35.2[a]	15.6[a]	12.0[a]	7.5[a]
(b) Age				
5–15 years[a]	47.6	15.6	12.1	7.4
5–15 years[b]	4.7	17.4	14.8	6.8
15–35 years[a]	29.9	16.4	13.2	7.2
15–35 years[b]	45.6	18.8	15.4	8.0
35–45 years[a]	9.3	15.8	12.6	7.0
35–45 years[b]	23.9	18.4	15.0	7.8
45+ years[a]	13.2	15.7	12.6	7.0
45+ years[b]	25.8	18.0	14.8	7.6

[a]Walking trips.
[b]Bicycling trips.

senger catchment area (zone of influence of bus stops) by considering the detour factor, which is the ratio of actual walking distance to the airline distance. Seneviratne (1985) has evolved a more definite approach for finding critical pedestrian walking distances in a central business district, while analyzing the impact of various factors on walking distances. He identified a set of characteristics that influence the distribution of walking distances. According to the author, the critical distance is the distance at which the rate of change of the slope of the frequency distribution curve of the walking distance for the group of the people is the greatest. Koushki (1988) studied the effect of various influential characteristics on walking distances. He concluded that the knowledge of pedestrian characteristics could effectively assist in the optimization of policies concerning urban land use and locational distribution of transport-related facilities in rapidly growing urban areas of developing nations.

This paper reports on some findings with regard to the factors affecting

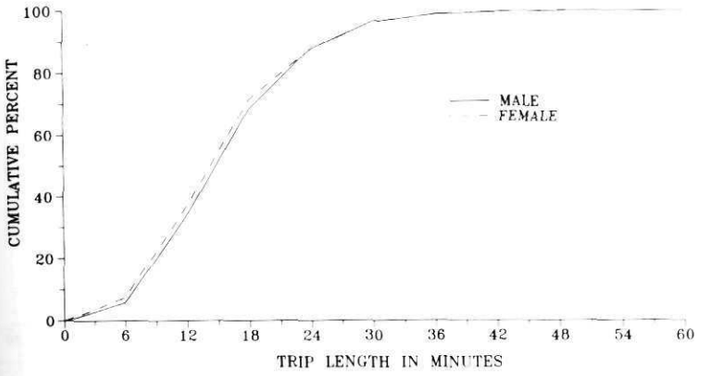

FIG. 1. Cumulative Frequency Distribution of Trip Lengths by Walking for Males and Females

length of home-based trips by foot and bicycle under Indian conditions. The means of determining acceptable trip lengths, which in turn could be incorporated in the urban facility-location process, has also been discussed.

DATA SET

The data used in this study were derived from the data of home-interview survey recently conducted for the purpose of comprehensive transportation planning for Tiruchirapalli in Tamilnadu State, India. The population of the study area (city and suburban areas) is about 1,000,000. Bus is the only public-transport mode available in the city. Taxi, auto rickshaw, and cycle rickshaw are the intermediate public-transport modes used. The average household size of the city is 4.9 and car ownership is 5.3 per thousand households. Motorized two-wheelers are also extensively used in the city and ownership of this vehicle is 58.2 per thousand households. Most of the trips in the area are made for work and school purposes constituting about 50% and 40% respectively of the total trips. The modal split of the home-based trips of the area is furnished in Table 1. The whole of the database includes information on household and socioeconomic characteristics and trips made by the members of households. For the purpose of this study, a data file containing information on age, sex, occupation, trip purpose, time of day of travel, and trip length was prepared by taking samples from the original data. The samples were picked randomly using a random number generator formulated by Press (1988). Samples of 3,000 observations for walking trips and 2,000 for bicycling trips were processed and made ready for further analysis.

INFLUENCING FACTORS

The pattern of length of trips by different modes depends on several influencing factors. The propensity of people to make trips by foot and bicycle depends on the socioeconomic characteristics of the individuals in addition to other factors like age, sex, trip purpose, occupation, and time of day of travel. The influence of these factors on home-based trips by these two modes has been analyzed.

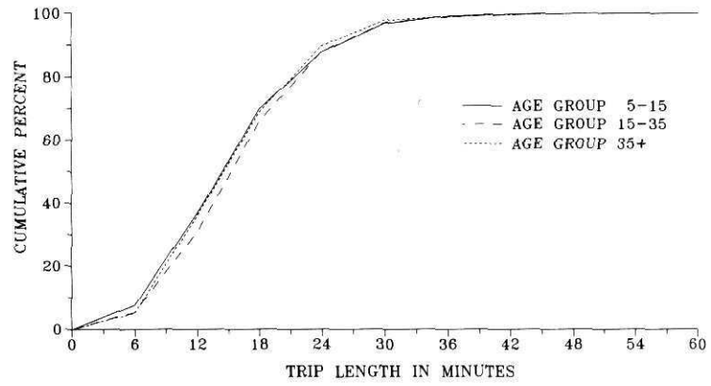

FIG. 2. Cumulative Frequency Distribution of Trip Lengths by Walking for Different Age Groups

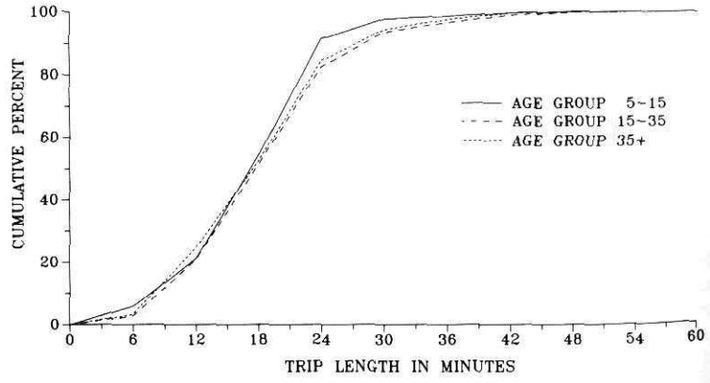

FIG. 3. Cumulative Frequency Distribution of Trip Lengths by Cycling for Different Age Groups

Age and Sex

Trip lengths, considering walking and bicycling trips separately, were analyzed based on sex and four age groups, 5–15 years, 15–35 years, 35–45 years, and over 45 years. The basic statistics of the trips made by the two modes are furnished in Table 2. The bicycling trips by female, being negligible, were not considered separately for the analysis. Cumulative frequency distribution curves were drawn to study the variation of frequency of trips over trip length. Fig. 1 illustrates the distribution of length of walking trips based on sex. As the cumulative distributions for age groups 35–45 years and over 45 years were found to be almost the same, these two were combined into one group as "35+" for the purpose of drawing the curves. Figs. 2 and 3 show the distribution of walking and bicycling trip lengths respectively for the three age groups. It can be inferred from these curves that for a given percentile value, the trip length for females is less than that for males (Fig. 1), and the trip length is, up to certain value, for age group 5–15 years the least and that for age group 15–35 years maximum (Figs. 2

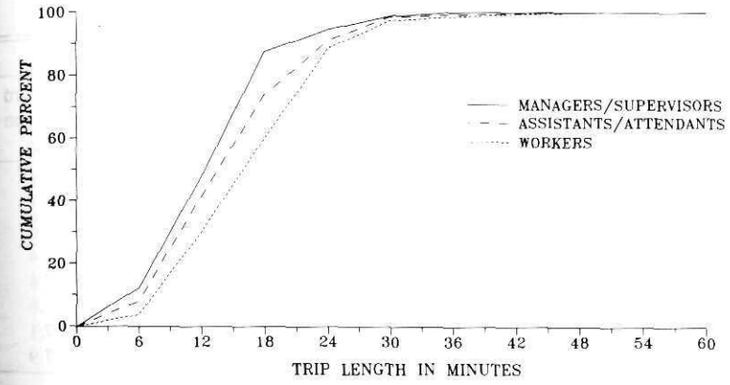

FIG. 4. Cumulative Frequency Distribution of Trip Lengths by Walking for Different Occupational Groups

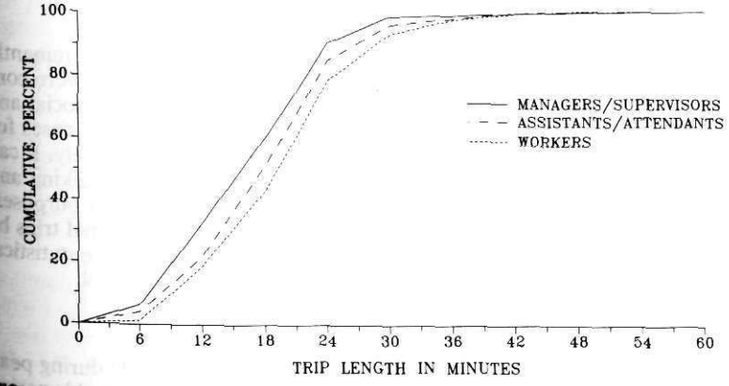

FIG. 5. Cumulative Frequency Distribution of Trip Lengths by Cycling for Different Occupational Groups

and 3). However, when statistically tested (Benjamin and Cornell 1970), there was no significant difference between these categories at 5% level of significance.

Occupation

The occupational groups considered were managers/supervisors, assistants, attendants, and workers. As the cumulative distributions of trip lengths of assistants and attendants were found to be nearly the same, these were combined into one group as assistants/attendants. The cumulative distributions of trip length for the three categories managers/supervisors, assistants/attendants, and workers are shown in Figs. 4 and 5 for walking and bicycling trips, respectively. It can be observed that higher-level occupational groups travel lesser distances by both modes than lower-level occupational groups. The statistics of trip lengths for these categories are shown in Table 3. When statistically tested, it was found that the mean trip lengths of the three groups were significantly differing at 5% level of significance.

TABLE 3. Trips Made by Different Occupational Groups

Occupational group (1)	Proportion of trips (%) (2)	Trip Length in Minutes		
		Mean (3)	Mode (4)	Standard deviation (5)
Managers/supervisors[a]	34.2	13.5	10.2	6.1
Managers/supervisors[b]	28.0	17.0	15.0	8.3
Assistants[a]	14.6	15.0	11.6	6.6
Assistants[b]	23.8	18.3	16.3	7.4
Attendants[a]	8.0	15.1	11.6	7.4
Attendants[b]	6.7	18.7	16.8	7.6
Workers[a]	43.2	17.3	13.8	7.1
Workers[b]	41.5	20.2	17.9	7.9

[a]Walking trips.
[b]Bicycling trips.

Trip Purpose

Based on the different purposes for which trips are made predominantly by the two modes in the study area, the following trip purposes were considered for analysis: (1) Work and business; (2) school; and (3) social and recreational. Cumulative distribution curves drawn for the three cases for walking and bicycling modes are shown in Figs. 6 and 7, respectively. It can be seen that at any percentile value, the trip length by both walking and bicycling, for work and business is higher than that for the other purposes. It can also be observed that majority of the social and recreational trips by the two modes are made to comparatively nearer destinations. The statistical details of trip lengths for the three cases are provided in Table 4.

Time of Day of Travel

In general, most of the work trips and school trips are made during peak hours, whereas trips for other purposes are spread over a considerable period of the day. During midday, mostly, the trips will be return-home trips for lunch either from place of work or school. As the trip-length pattern of these are different, there will be differences in the distributions. Hence, trips made during the following periods of the day were considered for analysis: (1) Morning peak (8:00 a.m.–10:00 a.m.); (2) midday (12:00 m.–2:00 p.m.); (3) evening peak (4:00 p.m.–6:00 p.m.); and (4) other period. During the analysis, it was found that the distribution of trip lengths during morning and evening peak periods did not differ much; and hence, the trips during the two peaks were combined and considered as "peak-period trips." In the case of walking trips, there was no considerable difference between the distributions of peak- and other-period trips. Hence, cumulative distribution curves for only peak periods and midday were drawn (Fig. 8). It can be observed that for any percentile value, the trip length during midday is less than the corresponding trip length during peak period. This is probably because people return home by foot for lunch when their home is nearer to their workplace. A similar trend can be observed in Fig. 9, which illustrates the variation of bicycle trip length during peak periods, midday, and other period. Table 5 provides a summary of statistics for the trips of these categories.

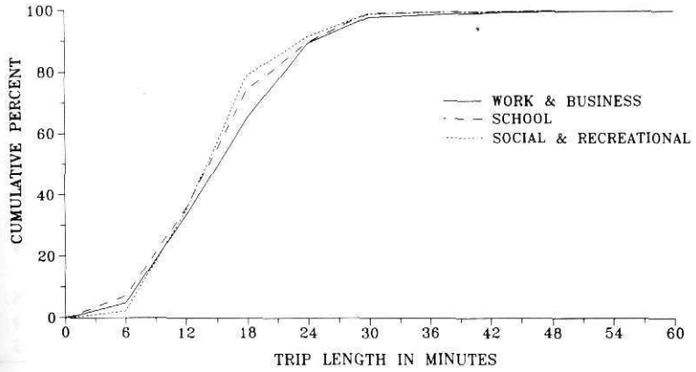

FIG. 6. Cumulative Frequency Distribution of Trip Lengths by Walking for Different Purposes

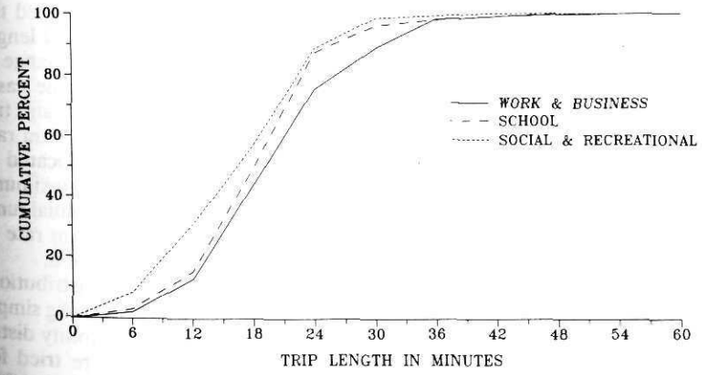

FIG. 7. Cumulative Frequency Distribution of Trip Lengths by Cycling for Different Purposes

CRITICAL TRIP LENGTH

Slow modes (walking, bicycling), obviously, are not used for longer trips. Hence, there will be a maximum trip length by each of these modes before which a person chooses a faster mode for travel. Also, the trip length and hence the maximum trip length, varies with respect to the socioeconomic characteristics of the trip makers and trip type. Hence, for each category of trip, there will be an acceptable maximum trip length, the information about which will be useful in locating activity centers in an urban area. Cumulative distributions shown in Figs. 1–9 represent the proportions of trips at any point with length shorter than the trip length shown. Thus, the slope of the cumulative frequency distribution curve at any given trip length will give the number (the proportion) of people that would be affected by a change in the trip length (Seneviratne 1985). A closer examination of the rate at which the slope of the cumulative distribution is changing will enable one to determine the point at which this rate is maximum. At this point, even a small change in trip length will affect the greatest number of trip

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TABLE 4. Trips Made for Different Purposes

Trip purpose (1)	Proportion of trips (%) (2)	Trip Length in Minutes		
		Mean (3)	Mode (4)	Standard deviation (5)
Work[a]	34.5	16.7	13.0	7.1
Work[b]	78.3	18.8	15.8	7.9
School[a]	58.2	15.4	12.3	6.6
School[b]	13.4	18.5	15.1	6.9
Business[a]	4.7	16.7	14.3	6.4
Business[b]	7.5	19.0	17.0	7.8
Social and recreational[a]	2.6	15.1	12.8	5.9
Social and recreational[b]	0.8	18.0	14.3	8.3

[a]Walking trips.
[b]Bicycling trips.

makers, and the trip length corresponding to this point is thus called the "critical trip length." With the objective of determining the critical length for different trip types considered, the point of maximum rate of change of slope in each of the cumulative distribution curves, in all the nine cases (Figs. 1–9), were located, and the corresponding percentile value and trip length (critical trip length) were found. Here, the point of maximum rate of change of slope on the cumulative distribution curves were located as the point at which the rate of decrease of slope of the curve is maximum. Each of the cumulative distributions were fitted to suitable polynomial functions, and calculus was then used to locate the point of maximum rate of change of slope. The values thus obtained are furnished in Table 6.

If the observed trip-length data follow a standard probability distribution, then the critical trip length can be found more easily by directly using simple calculus. To explore this possibility, two commonly used probability distributions for the purpose, gamma and normal distributions were tried for fitting the observed data of trip length. A preliminary analysis revealed that only the following three cases may nearly fit in the theoretical distributions: (1) Walking trips by male; (2) walking trips by female; and (3) bicycle trips. The fitting of the data into the normal distribution being simpler, the same was done without the aid of a computer program. However, considering the nature of calculations involved in fitting the data in gamma distribution, a computer program was developed and used to fit the data into gamma distribution. The accuracy of the program was checked by comparing the incomplete gamma values calculated using the program with the corresponding approximate values available in the tables for incomplete gamma function prepared by Pearson. When the three cases were tried with the two distributions, it was found that the data, in all three cases, fitted the gamma distribution better than the normal distribution. The fitting of the data for one of the three cases, walking trips by female, is illustrated in Fig. 10. The parameter values of the distributions estimated by the method of moments, and the goodness-of-fit statistics are shown in Table 7.

The critical trip length in the case of gamma distribution is calculated as follows.

The slope of the cumulative distribution function $F(x)$ is

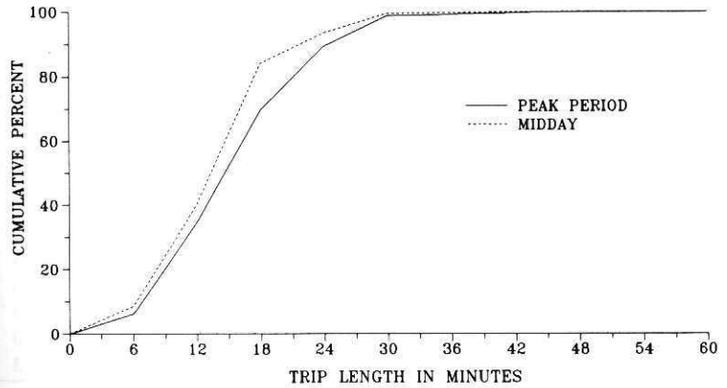

FIG. 8. Cumulative Frequency Distribution of Trip Lengths by Walking at Different Times of Travel

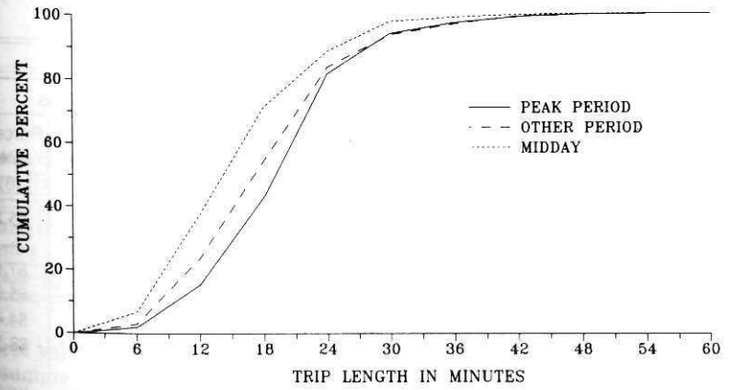

FIG. 9. Cumulative Frequency Distribution of Trip Lengths by Cycling at Different Times of Travel

$$\frac{dF(x)}{dx} = \frac{\lambda(\lambda x)^{\alpha-1}e^{-\lambda x}}{\Gamma(\alpha)} \quad \ldots\ldots (1)$$

in which x = trip length; and α and λ = distribution parameters. Since the objective is to determine the maximum rate of change of slope, the second derivative of $F(x)$ must be considered. Hence

$$\frac{d^2F(x)}{dx^2} = \frac{\lambda^{\alpha}[(\alpha-1)x^{\alpha-2}e^{-\lambda x} - x^{\alpha-1}\lambda e^{-\lambda x}]}{\Gamma(\alpha)} \quad \ldots\ldots (2)$$

Eq. (2) has to be maximized in order to obtain the value of x at which the rate of change of slope is maximum. Differentiating (2) once and equating it to zero, we obtain the value of x as

$$X_{\text{critical}} = \frac{(\alpha-1) \pm \sqrt{(\alpha-1)^2 - (\alpha-1)(\alpha-2)}}{\lambda} \quad \ldots\ldots (3)$$

TABLE 5. Trips Made During Different Times of Day

Time of day (1)	Proportion of trips (%) (2)	Trip Length in Minutes		
		Mean (3)	Mode (4)	Standard deviation (5)
Morning peak[a]	34.3	15.9	12.8	6.8
Morning peak[b]	23.0	19.6	16.9	7.3
Evening peak[a]	27.5	15.7	12.7	6.7
Evening peak[b]	19.0	19.5	16.1	7.9
Midday[a]	26.9	15.7	12.4	7.0
Midday[b]	47.9	18.7	14.9	7.9
Other period[a]	11.3	14.0	11.4	6.0
Other period[b]	10.1	15.5	12.1	7.3

[a]Walking trips.
[b]Bicycling trips.

TABLE 6. Critical (Acceptable) Trip Length

Trip Details		CRITICAL TRIP LENGTH					
		Walk Trips			Bicycle Trips		
Group (1)	Subgroup (2)	Minutes (3)	Meters (4)	Percentile (5)	Minutes (6)	Meters (7)	Percentile (8)
Sex	male	20.2	1,616	77.2	23.0	4,600	75.8
Sex	female	19.4	1,358	76.1	—	—	—
Age	5–15 years	20.0	1,560	77.2	23.9	4,780	87.6
Age	15–35 years	21.3	1,661	80.2	24.8	4,960	85.1
Age	35+ years	20.9	1,630	80.8	24.8	4,960	84.4
Occupation	managers/supervisors	17.2	1,342	83.1	24.0	4,800	88.5
Occupation	assistants/attendants	19.3	1,505	78.6	25.2	5,040	86.3
Occupation	workers	23.7	1,849	85.0	26.5	5,300	86.5
Purpose	work and business	22.7	1,771	85.0	26.0	5,200	81.0
Purpose	school	19.9	1,552	80.6	24.9	4,980	88.0
Purpose	social and recreational	19.1	1,490	81.5	25.0	5,000	89.5
Time of day	peak period	20.9	1,630	81.1	25.8	5,160	84.5
Time of day	midday	18.9	1,474	85.0	19.8	3,960	77.4
Time of day	other period	—	—	—	24.4	4,880	84.0

Note: The critical trip lengths in meters have been arrived at assuming a walking speed of 80 m/minutes for male, 70 m/minutes for female, and 78 m/minutes for travelers in other categories, and a speed of 200 m/minutes for trips by bicycle considering the roadway and traffic conditions in Indian cities.

The critical trip length can be calculated using (3) if the values of α and λ are known. For example, considering walking trips by females, the gamma distribution parameters, as given in Table 7, are $\lambda = 0.28$ and $\alpha = 4.36$.

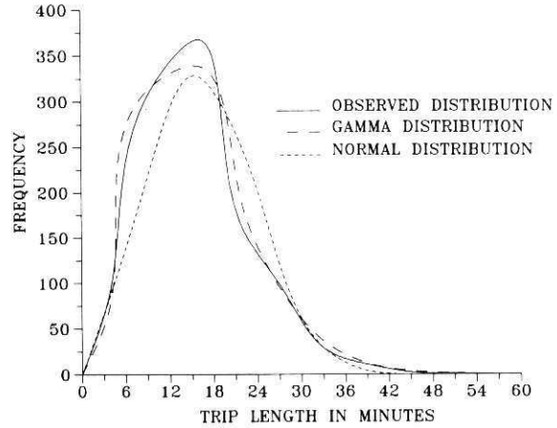

FIG. 10. Probability Distribution of Trip Lengths by Walking for Females

TABLE 7. Statistics of Distributions Fitted to Trip Patterns

Mode of trip (1)	Normal Distribution				Gamma Distribution			
	Mean (2)	Standard deviation (3)	χ^2 (4)	Degrees of freedom (5)	α (6)	λ (7)	χ^2 (8)	Degrees of freedom (9)
Walking (Male)	16.1	7.3	124.1 (12.6)	6	4.80	0.299	14.3 (14.1)	7
Walking (Female)	15.6	7.5	91.8 (11.1)	5	4.36	0.280	13.4 (12.6)	6
Bicycling	18.8	8.2	64.1 (12.6)	6	5.25	0.280	7.5 (14.1)	7

Note: Figures in parentheses are the table values at 5% level of significance.

These values when substituted in (3) yield 18.60 minutes as the trip length. Assuming a walking speed of 70 m/minute (Tanaboriboon et al. 1986), the critical walking distance for females will be 1,302 m, say 1.3 km. Adopting a walking speed of 80 m/min (Fruin 1971) and a bicycling speed of 200 m/min, the critical trip lengths for walking trips by males and for bicycling trips were found to be 19.23 minutes and 22.55 minutes, respectively. The percentile values for walking trips by males, walking trips by females, and bicycling trips were found to be 72, 72, and 75, respectively. It can be seen that these values are close to the ones found from the cumulative frequency distribution curves.

CONCLUSIONS

The analysis of urban trips by foot and bicycle modes will enable understanding of certain characteristics of these trips that will be useful in deciding the relative location of different land uses in an urban area. The mean trip length found for different categories of trips is an useful information in understanding the existing travel pattern by the two modes in the study area and in other similar cities. The distribution of trip length for different types of trips illustrated by the cumulative frequency distribution curves (Figs. 1–9) augments the information on the travel pattern. The critical trip lengths derived from the curves indicate the acceptable trip lengths for different

groups of travelers, and this information will serve as a very useful guideline in the planning of facilities related to home-based trips made by walking and bicycling. Also, from critical trip lengths, one can find the catchment of a facility, where trips are generated by slow modes in an urban area. For example, the zone of attraction of trips by walking and bicycling modes for a school in an urban area can be found if the critical trip lengths for these modes are known.

The analysis of the home-based trips in the study area reveals that, on the whole, the critical length of trips are about 20 minutes and 24 minutes by foot and bicycle modes, respectively. The average percentile value of the cumulative distribution curves that correspond to the average critical trip lengths are 81% and 85% for walking and bicycling modes, respectively. Thus, under the stated conditions, the acceptable trip length in an urban area can be found by taking the 81 and 85 percentile values of the cumulative distribution curve of walking and bicycling trips respectively.

The trip data may be fitted into theoretical distributions, as illustrated in this paper, wherever possible, so that the characteristics of the trips may be directly obtained by simple calculus. This method will be particularly useful when the available information is limited. Fitting the trip data into theoretical distributions will also facilitate extension of the analysis and application of the results in a wider spectrum. For example, trip-length frequency distribution curves that are necessary for calculation of travel time factor in trip distribution analysis can be drawn using an appropriate theoretical distribution for an urban area in the absence of relevant field data.

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APPENDIX II. NOTATION

The following symbols are used in this paper:

$dF(x)/dx$ = first derivative of cumulative distribution function $F(x)$;
$d^2F(x)/dx^2$ = second derivative of cumulative distribution function $F(x)$;
$F(x)$ = cumulative distribution function of trip length;
x = trip length;
α = shape parameter of gamma distribution; and
λ = scaling parameter of gamma distribution.

HEURISTIC ALGORITHMS FOR AGGREGATING RAIL-SURFACE-DEFECT DATA

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(Reviewed by the Highway Division)

ABSTRACT: An optical inspection system has been developed to detect the presence of defects on the surface of rails. The system classifies each 6 in. (15 cm) length of railhead as defective or nondefective and generates large quantities of disaggregate, sequential condition data. Defective rail surfaces can then be corrected by grinding the surface of the rail. However, this requires that condition data be aggregated to a level suitable for making maintenance decisions, and that prior recognition be given to practical constraints such as adjusting minimum grinding length to the configuration of the particular grinding machine. Data-aggregation procedures range from rule-based techniques to mathematical optimization methods. This paper reviews these aggregation techniques and, consequently, formulates the grinding problem as a set-packing integer programming formulation. Two heuristic solution methods are proposed to solve a set-packing problem of high dimension resulting from a large number of feasible packs for rail-surface-condition data. These methods effectively moderate the computational intensiveness and time complexity associated with using existing procedures.

INTRODUCTION

The development of systems to automatically acquire condition data for transportation facilities has enabled maintenance managers and planners to effectively monitor the condition and maintenance needs of the structure. Condition data can now be collected at high speed using a variety of sensors. These data are used by maintenance experts to determine when and where to maintain or replace all or specific sections of the facility. However, raw condition data is often very disaggregate compared to the level of aggregation required for maintenance decision making.

Processed rail surface data are typically used to determine grinding strategies and understand patterns of rail surface deterioration. A prototype video data collection and image processing system was developed at Carnegie Mellon University for detecting defects on the surface of the rail (McNeil et al. 1991). The system can identify the presence or absence of defects on a frame-by-frame basis, where each frame represents 6 in. (15 cm) of rail. Surface defects on the rail are known to increase the dynamic impacts of the wheels of the train on the rail, resulting in premature rail replacement and reduced life of other components of the track (Zarembski 1984). The problems can be corrected by grinding the rail. North American railroads spend about $15,000,000 annually for grinding alone. One of the major North American railroads, Burlington Northern Railroad, has experienced unusually high incidences of fatigue-related surface defects on its mainline tracks and has been very aggressive in grinding out these defects (Glavin 1989). In 1986, Burlington Northern ground approximately 24,000

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